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SUPPRESSING RELAY COIL TRANSIENTS WITH BIFILAR WINDING

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ABSTRACT

The voltage spike generated by the collapsing field of an electromagnetic relay coil may reach a potential of over 1000 volts. This transient, if not suppressed, may cause malfunction or damage in the associated circuit, particularly in the device used to deenergize the relay coil. This paper briefly explains bifilar winding of the relay coil as a technique for transient suppression. A comparison is made between this and other techniques. The conclusion is drawn that bifilar winding is the superior method for aerospace applications.

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SUPPRESSING RELAY COIL TRANSIENTS WITH BIFILAR WINDING

by

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ELECTRICAL SYSTEMS INTEGRATION DIVISION
ASTRIONICS LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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TECHNICAL MEMORANDUM X-53276

SUPPRESSING RELAY COIL TRANSIENTS WITH BIFILAR WINDING.

SUMMARY

The voltage spike generated by the collapsing field of an electromagnetic relay coil may reach a potential of over 1000 volts. This transient, if not suppressed, may cause malfunction or damage in the associated circuit, particularly in the device used to deenergize the relay coil. This paper briefly explains bifilar winding of the relay coil as a technique for transient suppression. A comparison is made between this and other techniques. The conclusion is drawn that bifilar winding is the superior method for aerospace applications.

SECTION I. INTRODUCTION

Transients may be suppressed at each of the devices to be protected or at the source, i.e., the relay coil itself. Suppression at the devices to be protected is bulky and uneconomical.

Suppression at the relay coil is usually called shunt suppression because it employs resistors, capacitors, diodes, or combinations of these, shunted directly across the coil. Bifilar winding is a type of shunt suppression.

RC suppression is impractical for space applications because of the large size and poor high-temperature characteristics of the components.

Diode suppression inside the relay is also impractical because of poor resistance to high temperatures. In addition, the diode tends to outgas at high temperatures and thus affect contact resistance.

The suppression effect of slugs, sleeves, and concentric coils is only about one tenth that of bifilar winding.

Bifilar winding, in which two wires are wound side by side throughout the coil, forms two closely coupled coils of the same number of turns on the same bobbin. One of these coils actuates the relay; the other, called the suppress coil, is usually shorted inside the relay case (Fig. 1).

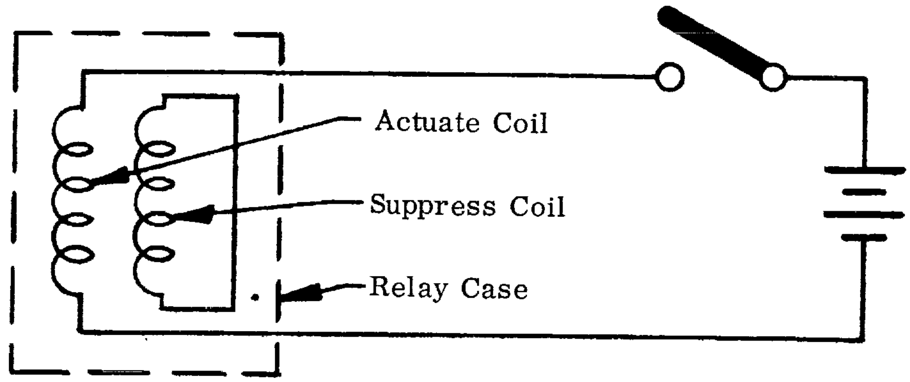

FIGURE 1. BIFILAR WINDINGS SUPPRESSION.

SECTION II. COMPARISON OF METHODS

To show the superiority of bifilar suppression as applied to space equipment, the characteristics of other types of shunt suppression will be briefly described.

A. RC SUPPRESSION

Capacitive or resistive-capacitive suppression is shown in Figure 2. This approach was probably the first solution to the transient problem that was widely used by circuit designers. The resistor is necessary, in most applications, to limit the current surge drawn by the capacitor through the switching device while energizing the relay.

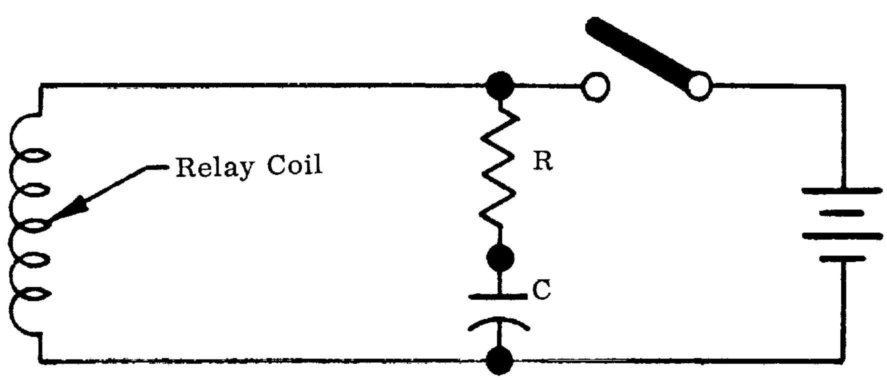

FIGURE 2. RC SUPPRESSION.

To obtain adequate suppression in space use, capacitors of large value — dictating large physical size — are required. Smaller tantalum capacitors would place a temperature limitation on the circuit designer. For polarized tantalum capacitors, this suppression becomes polarity dependent.

From the standpoint of both size and temperature, this type of suppression inside the case of most relays is highly impractical for space applications.

B. DIODE SUPPRESSION

Diode suppression is at present the most widely accepted method of shunt suppression of transients. This method may take one of several forms. It may incorporate a single shunt diode, a diode in series with a resistor, a regular diode in series with a Zener diode, or two Zener diodes in series, "back-to-back." These variations are shown in Figures 3 through 6.

The single shunt diode (Fig. 3) provides probably the highest degree of coil voltage suppression used today. However, it is often not desirable to suppress the transient voltage of a relay to this extent because transients are suppressed at the expense of certain relay parameters. The one most affected is the release time, or dropout time, of the relay. The more a relay is suppressed, the longer its release time will be; therefore, to reduce the effect of suppression on release time, the amount of suppression must be reduced. This can be done by placing a resistor in series with the diode (Fig. 4) or by placing a Zener diode in series with the regular diode (Fig. 5). The amount of suppression can then be varied by changing the resistance or by using Zener diodes with various breakdown voltages.

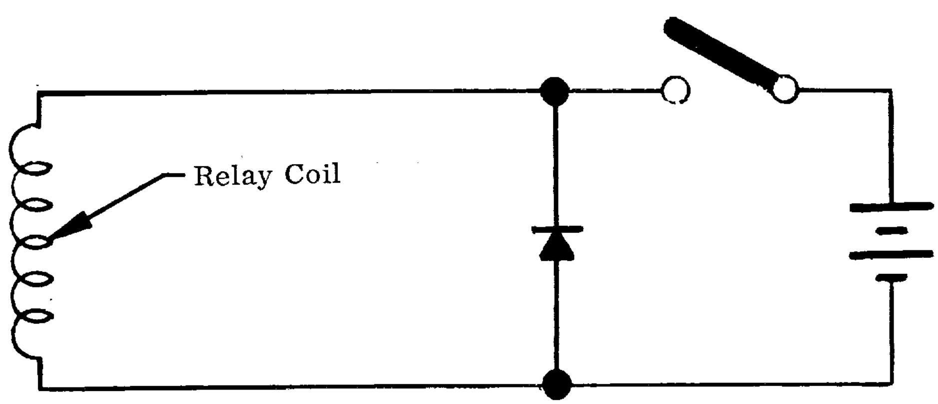

FIGURE 3. SINGLE DIODE SUPPRESSION.

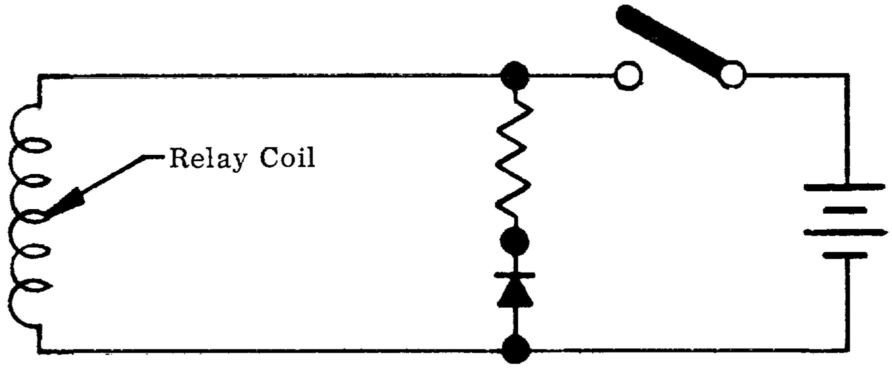

FIGURE 4. DIODE-RESISTOR SUPPRESSION.

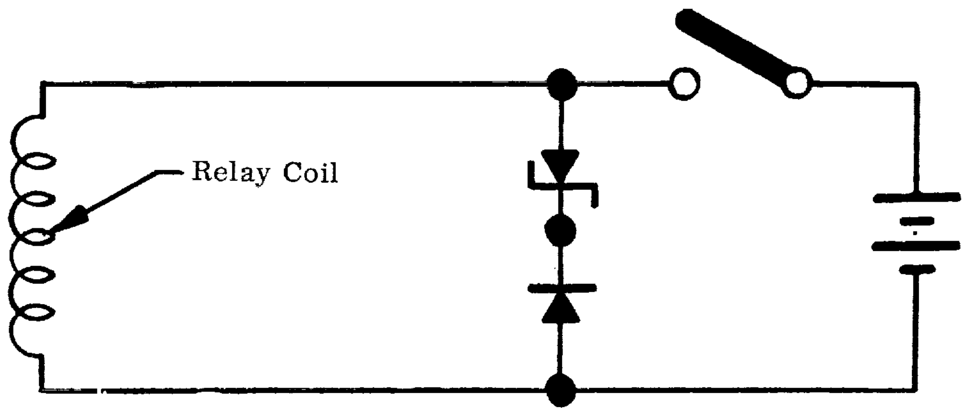

FIGURE 5. ZENER DIODE SUPPRESSION WITH BLOCKING DIODE.

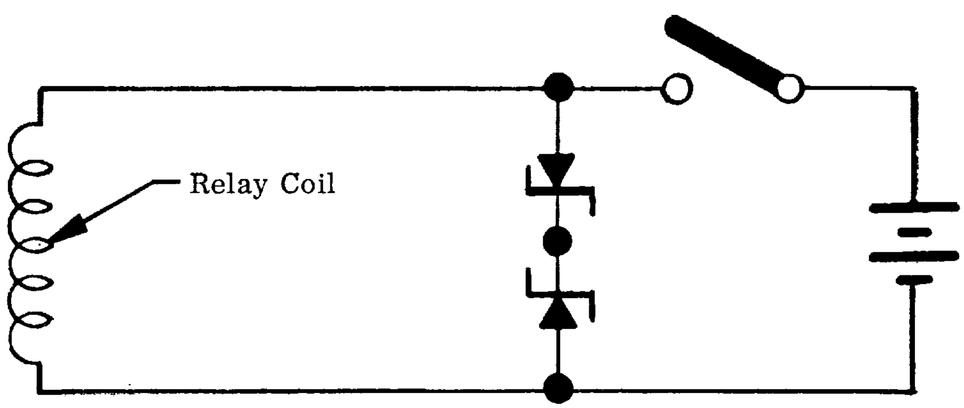

FIGURE 6. BACK-TO-BACK ZENER DIODE SUPPRESSION.

The circuit in Figure 6, using back-to-back Zener diodes, is similar to that of Figure 5, except that polarity of the energizing voltage across the coil need not be observed. With this arrangement, the diodes are not easily damaged by high peak inverse voltage transients coming from some external source that would ordinarily damage a conventional diode.

The breakdown voltage of the Zener diodes must, however, be maintained at some level higher than the energizing voltage so the Zener diodes will not draw excessive current while the coil of the relay is energized.

In all four of these circuits, two disadvantages of diodes inside the case of a relay are (1) the materials of most diodes are known to outgas enough to appreciably affect contact resistance at high temperatures and (2) temperatures inside a relay operating in an ambient temperature of 125° C can reach about 200° C, which is higher than the recommended maximum operating temperature of most diodes.

C. SUPPRESSION WITH SLUGS, SLEEVES, AND CONCENTRIC COILS

These devices are not as closely coupled to the operate coil as the bifilar winding and therefore do not suppress as well. Designed to delay the operation of the relay, they provide only about one-tenth the suppression of the bifilar winding.

D. BIFILAR WINDING SUPPRESSION

Bifilar winding suppression has several advantages over conventional types of suppression in space applications:

1. Bifilar suppression uses no materials different from those now used in conventional, nonsuppressed relays.

2. This method of suppression is effective at high temperatures seen inside the cases of relays operating in an environment of 125° C.

3. Since most manufacturers of relays for military and space use put the coils of their relays through a bake-out process before sealing the relay case (to drive out all possible moisture and gases which may form harmful deposits on the contacts of the relay, especially relays used in low-level or dry circuit applications), the bifilar suppression method would continue this process. This would eliminate further outgassing such as would probably occur with a diode inside the relay.

4. Bifilar winding is not polarity sensitive as are some types of diode shunt suppression.

5. Radiation hardening will possibly be extremely important in the near future, and bifilar-wound coils are readily adaptable to this use.

Bifilar-suppressed relays offer all these advantages and greatly increased reliability over conventional shunt suppression of relays.

Certain other parameters of the relay are also affected when the coil transient of a relay is suppressed with bifilar winding. As previously mentioned, the parameter most affected is the release time of the relay. With bifilar suppression, varying the amount of suppression to reduce the effect on the release time of the relay is very simple. If the wire size of the suppress coil is varied, the effective resistance of the suppress coil is also varied; thus the suppression is varied proportionately.

SECTION III. VOLTAGE WAVEFORM ANALYSIS

The following voltage waveform analysis shows the effects of bifilar suppression. The test setup in Figure 7 measured the transients of the various relays tested. The relay coil under test was deenergized with a mercury switch for best duplication of switching action.

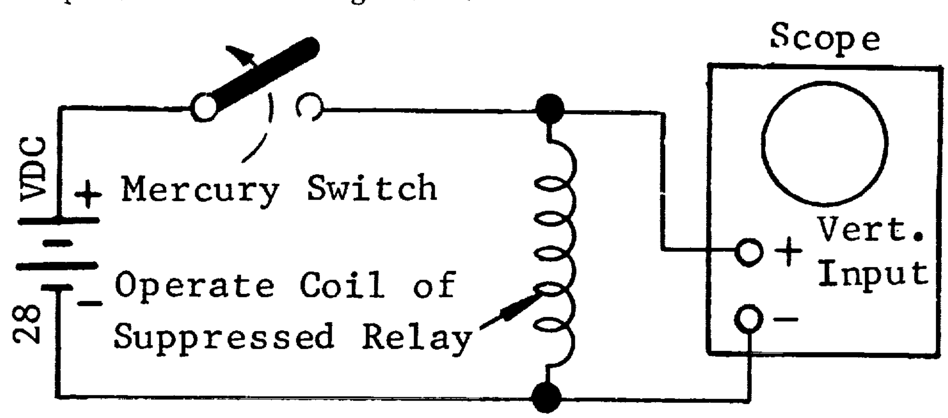

FIGURE 7. TEST SETUP USED FOR VOLTAGE WAVEFORM ANALYSIS.

Pictures of the traces produced by these transients were taken with a polaroid camera attached to the oscilloscope. Because of the very fast rise time obtained with the mercury switch, near-maximum transient traces were produced. Figure 8 shows the inductive transient of a nonsuppressed crystal can relay reaching an amplitude of 1100 volts. Typical release time of this relay is two milliseconds.

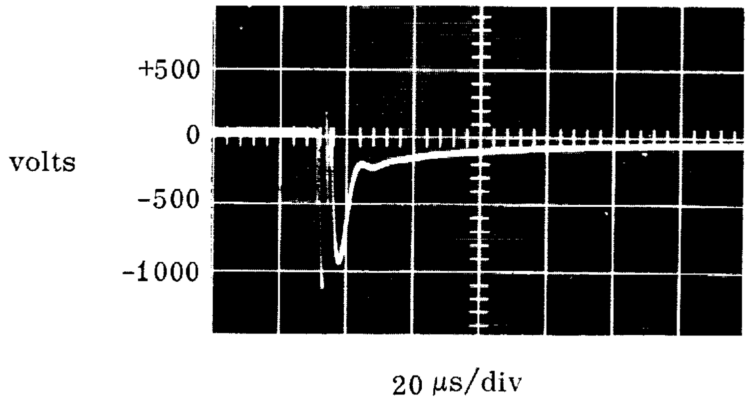

FIGURE 8. NONSUPPRESSED CRYSTAL CAN RELAY COIL TRANSIENT.

The transient of a crystal can relay suppressed with a single shunt diode is shown in Figure 9. Typical release time of this relay is 10 milliseconds. The negative voltage transient here is about 25 volts and of short duration.

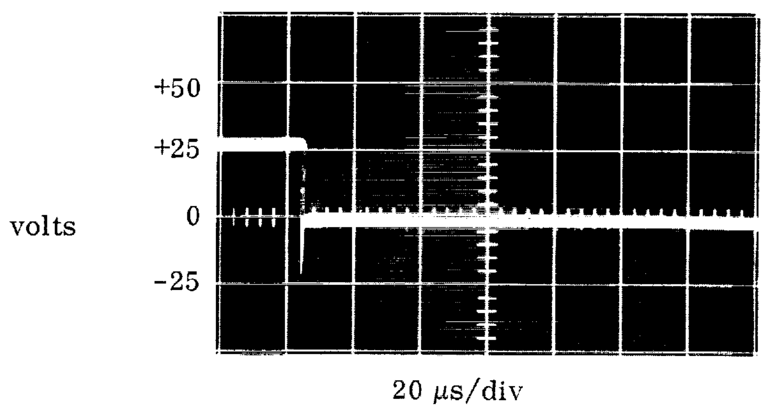

FIGURE 9. DIODE SUPPRESSED CRYSTAL CAN RELAY COIL TRANSIENT.

Different degrees of bifilar suppression obtained by using different wire sizes in the suppress coil are shown in Figures 10, 11, and 12. Figure 10 shows the transient obtained when the suppress coil uses the same size wire as the operate coil of the relay. The negative transient is about 25 volts. The release time of this relay is about six milliseconds.

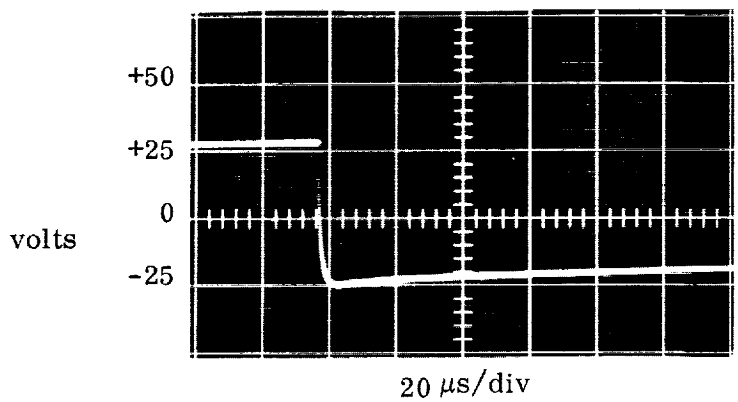

FIGURE 10. BIFILAR SUPPRESSION USING SAME SIZE WIRE IN SUPPRESS COIL.

Figure 11 shows the transient obtained when the suppress coil uses a smaller diameter wire than the wire in the operate coil. The transient shown here is approximately 40 volts. The release time of this relay is about four milliseconds.

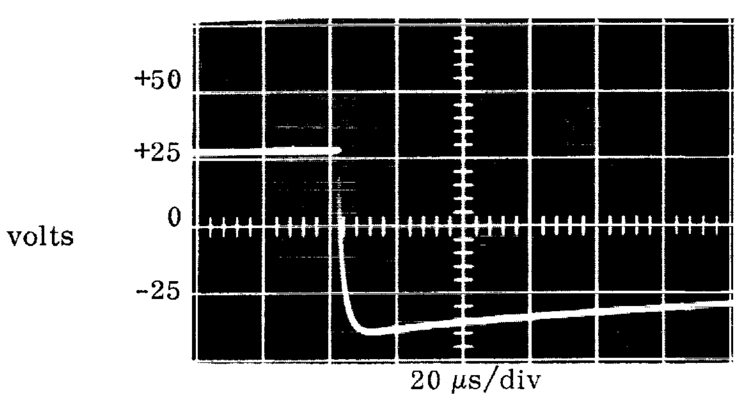

FIGURE 11. BIFILAR SUPPRESSION USING SMALLER SIZE WIRE IN SUPPRESS COIL.

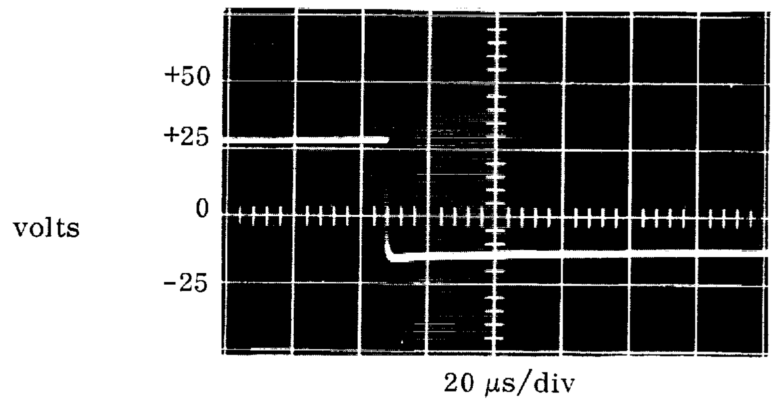

FIGURE 12. BIFILAR SUPPRESSION USING LARGER SIZE WIRE IN SUPPRESS COIL.

Figure 12 shows the transient obtained from a relay with a suppress coil wound with a larger diameter wire than the operate coil. The transient shown here is approximately 15 volts. The release time of this relay is typically eight milliseconds.

SECTION IV. RFI TEST RESULTS

Conducted RFI tests were performed in accordance with MIL-I-6181D to compare bifilar suppression with diode suppression. Figure 13 shows the circuit diagram and test setup.

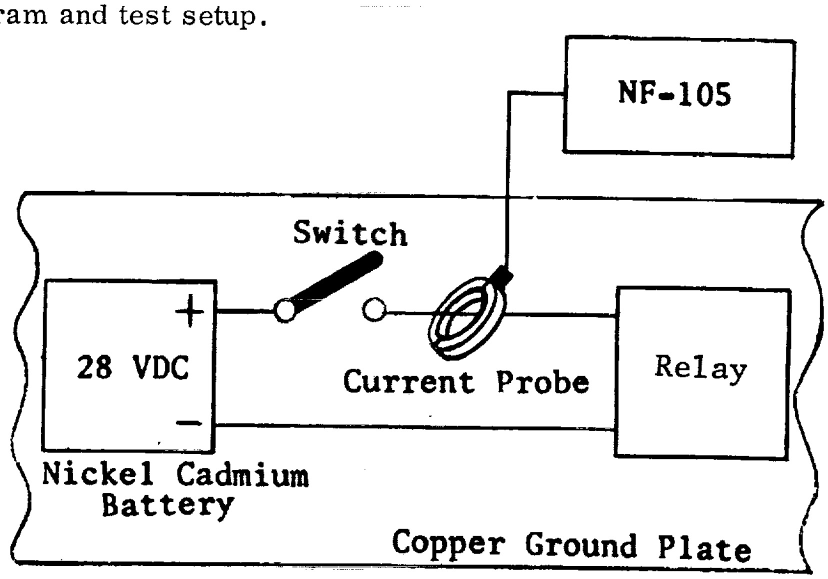

FIGURE 13. TEST SETUP USED TO MEASURE CONDUCTED RFI MEASUREMENTS OF RELAY COIL TRANSIENTS.

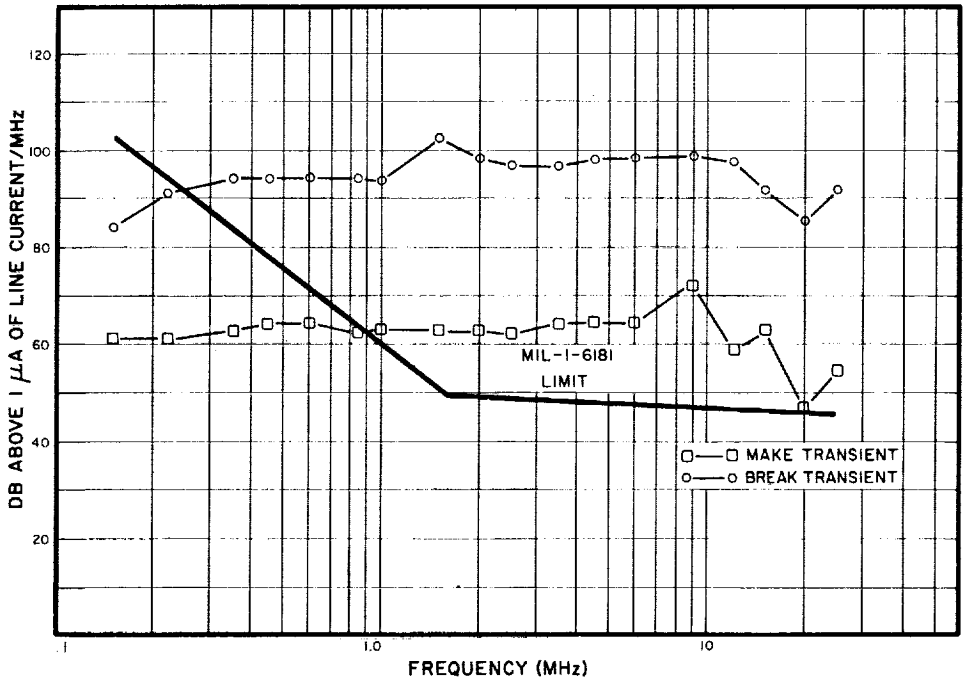

FIGURE 14. BROADBAND CONDUCTED RFI MEASUREMENTS (NONSUPPRESSED CRYSTAL CAN RELAY).

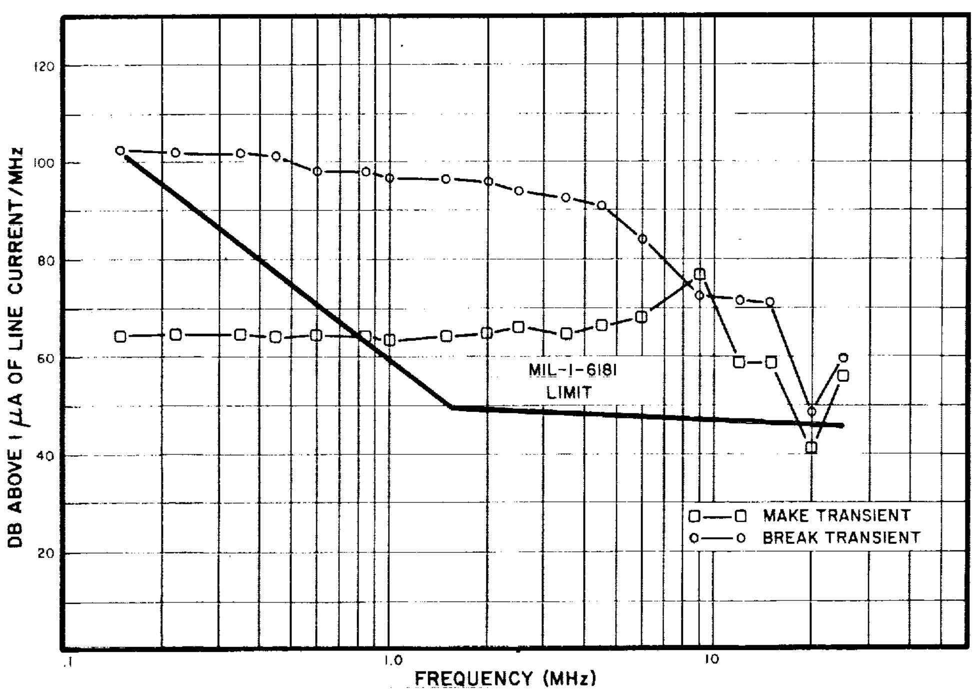

FIGURE 15. BROADBAND CONDUCTED RFI MEASUREMENTS (DIODE SUPPRESSED CRYSTAL CAN RELAY).

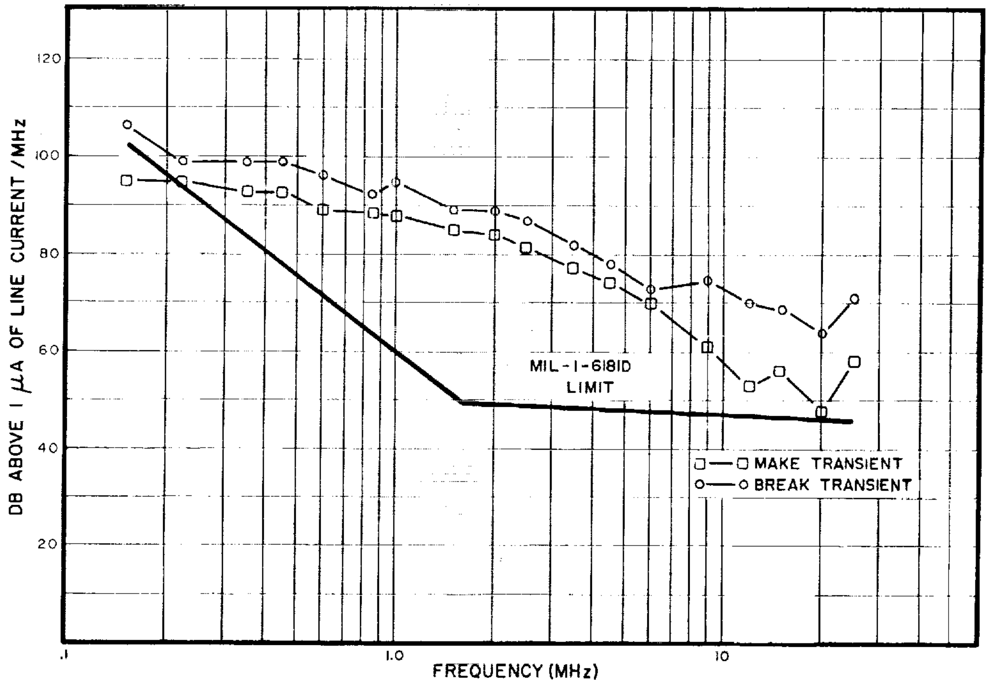

FIGURE 16. BROADBAND CONDUCTED RFI MEASUREMENTS (BIFILAR SUPPRESSED CRYSTAL CAN RELAY).

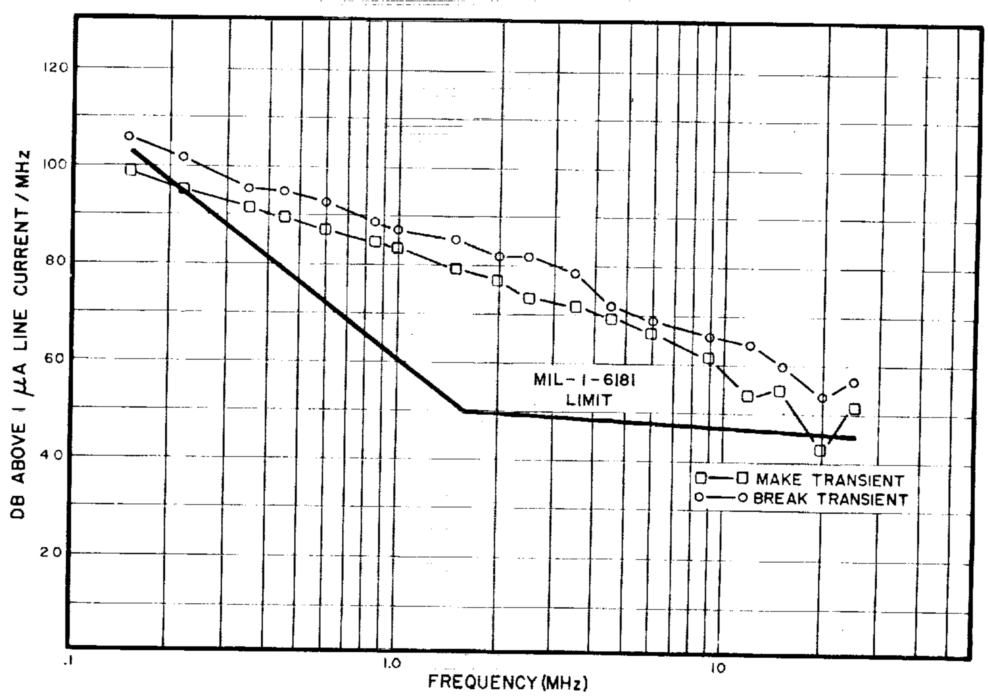

FIGURE 17. BROADBAND CONDUCTED RFI MEASUREMENTS (390 OHM CARBON COMPOSITION RESISTOR).

The results of these tests are shown in Figures 14 through 17, which show that the diode provides better suppression at the higher frequencies than at the lower frequencies. Although neither diode nor bifilar suppression provides enough attenuation to bring the RFI level below the limits of MIL-I-6181D, these graphs do show that bifilar suppression compares favorably with diode suppression.

RFI levels were obtained using a carbon composition resistor in place of the relay as a load. A comparison of Figures 16 and 17 shows that shunt-coil suppression makes the inductive coil of a relay appear as a purely resistive load. To further reduce the RFI levels measured here, suppression should be placed directly across the switching device.

SECTION V. DESIGN: PARAMETER TRADEOFF

Bifilar-wound relays have been provided by manufacturers for evaluation of performance and feasibility.

A. PHYSICAL SIZE

It was first believed that the physical size of the relays would have to be increased to make room for the additional wire on the coils of the relays. Another approach would be to have fewer turns on the operate coil, thus allowing space for the suppress coil. With fewer turns in the operate coil of the relay, there will be less resistance for a given wire size, and the current drawn by the relay will increase. This will allow the ampere turns of the relay to remain fairly constant, with an increase in steady state (I^2R) power consumed by the relay.

B. SENSITIVITY

It is evident from the statement above that bifilar winding will reduce the sensitivity of the relay if physical size remains constant. Also, the relay designer must consider the current-carrying capacity of the wire used in the operate coil and the ability of the relay to dissipate the heat generated by the additional excitation power used. If the relay cannot operate reliably with this decreased sensitivity, then a change in physical size of the relay may be in order.

C. OPERATE, RELEASE, AND TRANSFER TIMES

As stated earlier, release time of a relay is increased when a relay is suppressed. With increased release time comes an increase of release transfer time of the contacts. If transfer time is increased too drastically, the load life of the relay contacts would also be drastically reduced. This is true of any type of shunt suppression. On the other hand, the operate time of a suppressed relay is increased only a very slight amount, not enough to affect the load life performance of the relay.

D. DESIGN CRITERIA

After testing a great number of bifilar-wound relays with different amounts of suppression, an optimum design for relays to be used in the space field was determined.

One criterion is that the level of the maximum allowable transient under specification MIL-E-6051C should not exceed 1.5 times the peak power source voltage. This means that for a 28 volt relay a 42 volt negative transient is the maximum allowable.

It was found that if relays were suppressed to produce transients close to this value (between 30 and 42 volts) release time could be maintained at less than the maximum (six milliseconds for crystal can relays) allowed in MSFC-SPEC-339, which is the general specification for dc relays.

In the design of the bifilar coil, the suppress coil of the bifilar relay should contain wire approximately two AWG wire sizes smaller than the operate coil. For example, if the operate coil of a relay is wound with #45 wire, then the suppress coil must use #47 wire. This procedure provides the amount of suppression desired for MSFC use and has been used in winding coils of crystal can relays, large power contactors, and solenoid-actuated valves.

SECTION VI. RESULTS AND CONCLUSIONS

Exhaustive, full load, high temperature (125° C) life tests were run on bifilar-wound relays with the amount of suppression to produce 42-volt transients. The electrical characteristics of these relays were measured both before and after the life test. They passed these tests and showed just as good suppression after the test as before. The cases of these relays were then opened and measurements were made to determine if the operate coils had become shorted to the suppress coils of the relays. None of the relays developed shorts between the two coils.

MSFC has developed bifilar-wound relays that are suppressed to produce transients measuring approximately 42 volts. These relays are so designed as to have, as nearly as possible, the same characteristics as those now being used. Their electrical characteristics meet MSFC-SPEC-339. It is both desirable and feasible to use bifilar coil suppression on relays used in flight vehicles.

Different ratios of wire sizes in the operate and suppress coils of test relays produced no appreciable difference in RFI suppression. Bifilar coils having the same wire size in both windings, two wire sizes larger in the suppress coil, and two wire sizes smaller in the suppress coil all generated comparable RFI.

Future investigations will explore effects of bifilar-suppressed relays in system usage, e.g., whether the slower release time of these relays adversely affects timing sequences. Bifilar-suppressed relays will function faster than those suppressed with a single shunt diode, but slower than conventional, non-suppressed relays.

MSFC is promoting development of bifilar-wound coils not only in small relays, but also in power contactors and in solenoid-actuated valves. It is hoped that in the near future these devices may be used extensively in airborne electrical systems of launch vehicles designed or manufactured under supervision of MSFC.

APPROVAL TM X-53276

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R. M. Acker

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report has also been reviewed and approved for technical accuracy.

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